NOTES

1. Papers selected for inclusion in General Sessions will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

2. Papers selected for inclusion in Specialized Sessions will be available at the Conference in only one of the above official languages.

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INTEGRATED MINERAL EXPLORATION

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Introduction

1. The ultimate goals of minerals exploration are the discovery of important ore concentrations and their successful development to productivity of the elements and metals required by society. Present demands and future requirements for minerals and metals indicated by world-wide economic growth and increasing living standards is a compelling stimulus to the search for new ore sources. Competitive market conditions demand the highest standards of efficiency in this endeavor to ensure ultimate production at favorable costs. Superior techniques of discovery, mining, extraction and refining have helped lower the costs, thereby increasing potential ore targets and making possible the exploitation of mineral concentrations heretofore considered to be uneconomic.

2. Ore deposits generally are small targets when considered in terms of the vast regions in which they are found. The search for them truly resembles "looking for a needle in a haystack". As the importance of the historically colorful prospector, dependent upon persistence, good luck and visual recognition of rich mineralized outcrops gradually diminishes, valuable ore deposits become more difficult to find. Modern search must be expanded to include mineral concentrations that are not exposed at the surface but deeply buried and masked by alluvium or some other cover.

3. Unfortunately there are as yet no easy short cuts or "magic black boxes" which can lead infallibly to hidden mineral wealth. Successful ore development involves considerably more than the recognition of some anomalous condition in a regional geologic setting. Bringing a mineral deposit into production involves exploration costs, acquisition costs, investments in development and plant facilities, operating costs and marketing costs. The worth of the deposit must be measured in terms of producing income in excess of these costs.

4. In spite of the old adage that "ore is where you find it", distribution of minerals is not random, but is in orderly patterns related to geologic history of the earth's crust. Therefore an intelligent minerals exploration program must be based on understanding of the distribution of elements in the earth's crust and the processes by which they are concentrated into ore deposits. For example, recognition and appreciation of metallogenic provinces can be of utmost significance in exploration planning. Since commercial orebodies are restricted in size and present such small targets, scientific ore search must necessarily be a sorting process which starts with the consideration of broad areas. Gradually, through processes of evaluation, elimination and selection, the scope is narrowed to smaller target areas through scientific application of geological, geophysical and other tools and techniques available to modern prospecting. These target areas must be tested in the light of past knowledge and experience, as well as newer concepts involving a better understanding of ore genesis developed through modern scientific research and confirmatory field observations. The importance of accurate genetic geological concepts as basic guides for successful evaluation of the most likely sites for commercial ore cannot be over-emphasized.

5. Both government agencies and private mining companies have definite responsibilities toward minerals exploration, and only through integrated cooperative efforts can the ultimate goal, successful minerals production, be reached. Development of minerals industries will be stimulated by stable economic and political climates favorable to the required investment of large sums of risk capital over prolonged periods of time. An environment in which profit incentive can flourish will encourage private industry with attendant creation of employment and important sources of taxable income. Sound mining laws incorporating sound policies of adequate protection of rights and titles to discoveries with the assurance of sufficient time for their successful development, exploitation and marketing of production are fundamental prerequisites.

Regional Setting:

6. An initial requirement for comprehensive minerals exploration programs is determination of regional geological environment. Broad scale coverage by aerial photographic cartography and regional geologic mapping involving both photogeologic interpretation and field studies are steps in this direction. Regional geologic mapping, particularly when supplemented by application of various airborne geophysical methods, can provide basic background data on regional structures, extent and relationships of lithologic units, outlines of major intrusive masses and alteration zones.

7. Initial regional surveys of this nature are time-consuming and often too costly to be undertaken by individual mining companies. Since the usefulness of such surveys can be multiplied manifold when applied to numerous fields of endeavor, it is logical that in the community interest they be undertaken by government agencies and made available for public use. Such basic regional information will stimulate prospecting by numerous mining companies having diverse objectives in their appraisal and selection of target areas best suited for their individual purposes. Anomalies resulting from initial regional surveys may be both numerous and vague, however, and considerable further refinement and selection through scientific analysis and testing is required before discovery and development of an important mineral district or orebody can be consummated.

8. It is in this latter field of more specific target selection and analysis that private industry can best function efficiently. As the target areas become more restricted through prudent scientific selection there must be a continuing reappraisal of the program in the light of new geologic facts and a constant assessment of the chances of success in terms of the potential value of the target. Scientific application of modern techniques in the light of actual mining experience then becomes increasingly important to the successful development of an orebody. It is logical that private mining interests, motivated by profit incentive under a free enterprise system, can provide an efficient approach.

9. A brief review of the actual prospecting approach to two distinctive problems, both occurring in more or less unexplored regions but under widely differing conditions of geologic, topographic and climatic settings may prove interesting.

Case Histories:

a. In a shield area of sparse outcrop.

10. Figure I is a very broad scale regional geology map (original scale 1"=120 miles) of two provinces in the Precambrian Canadian Shield. Glacial till and alluvial cover is extensive but relatively shallow. Geological mapping by observation of outcrops, therefore, is necessarily sketchy and requires supplementary methods. Aerial photography for photo-geologic interpretation and direction of the field work is a distinct aid, whether or not outcrops are sparse. Probably multiple purpose aerial photography on a scale of the order of 1:62,500 would be satisfactory for regional geologic mapping as well as for fields of endeavor other than the mineral industry. Such a survey for an area of two million square miles would cost approximately $3.2 million. This much regional coverage is necessary in order to indicate more restrictive areas for application of any of the more expensive

supplementary methods of mapping geology, such as airborne magnetics and electromagnetics and ground gravity surveys. The regional geology control, in this case, presents approximate outlines of the sedimentary and volcanic belts which constitute the host rocks for metalliferous deposits in the Canadian Shield.

11. Figure II is an aeromagnetic contour map covering the sedimentary-volcanic belt from the Mattagami through the Chibougamau districts in Quebec. Maps on the scale of 1:62,500 were compiled and photographically reduced to produce this map on a scale of 1:250,000. The geologic detail indicated by the numerous magnetic-marker beds and igneous rocks is obvious. Figure II represents 11,800 square miles of aeromagnetic coverage out of many hundreds of thousands of square miles released to the public by Canadian government agencies at nominal print reproduction and distribution costs.

12. Concurrent interpretation of the above data (geologic maps, aeromagnetic maps and aerial photographs) by the mining company involved in this project resulted in a 1:250,000 scale improved regional geologic map. Structural and lithologic similarities were noted between the known mining districts and several relatively unexplored areas. Among the latter was the 310 square mile area marked 3 on Figure I and outlined in the center of Figure II.

13. Again, the above interpretational procedures were applied, but now on the more detailed scale of 1"=1 mile. A print of the geologic maps was assembled on this scale and only geologic features observed in outcrop were traced on a 1"=1 mile working print of the aeromagnetic map of this 310 square mile area. Concurrent interpretations of 1:62,500 aerial photographic contact prints in stereo pairs and of aeromagnetic data resulted in the geologic map shown on Figure III. The advantages of this simultaneous interpretational procedure are: (a) features on the aeromagnetic map serve to call attention to similar obscure features on the aerial photographs and vice versa; (b) integrated single features - such as dike lineaments - indicated on the aeromagnetic maps, may be resolved into multiple features on the aerial photographs; and, (c) interpretations between the two sets of data result in a higher degree of verification.

14. We should like here to emphasize the point of assembling all data and maps on the same scale for each step of exploration analyses. There is probably no clearer evidence of separated endeavors, rather than the desired integrated effort, by geologists and geophysicists than the display of data and maps on different scales.

15. The interpretational and analytical procedures employed by the mining company to advance to the stage illustrated by Figure III, required three months of work. Geological field checks requiring approximately three weeks verified the interpretations. The 310 square mile area was reduced to 115 square miles for geologic and property reasons and a contract for a helicopter-borne magnetic-electromagnetic survey was obtained. Specifications were one-eighth-mile flight line spacing, mean terrain clearance of 120 feet and blocks of variable flight azimuths at right angles to the general geologic structures. This survey - including weather and maintenance standby, data reduction and map compilation - required one month and cost $37,000. An example of a 60 square mile area of this survey is illustrated on Figures IV and V. Note the two flight line directions at right angles to geologic structure. Also, note the electromagnetic mapping of conductive graphitic and/or pyritic shales and schists, particularly in the north part of Figure V When magnetic marker-beds are sparse, electromagnetic surveys may serve to map conductive marker-beds and major faults with moderate to steep dips.

16. The original scale of Figures IV and V, the magnetic and electromagnetic data respectively, was 1"=1/4 mile. The concurrent interpretation procedure described above for the 1"=4 mile and 1"=1 mile maps was then applied, using these secondary airborne survey data, contact prints of stereo-pairs and geologic maps all to the scale of 1"=1/4 mile. A twelve square mile example of the resulting interpreted geologic map is exhibited on Figure VI. This interpretational step required 2-1/2 month's work, including an analysis and rating of 47 anomalous zones.

17. Note, on Figure VI, the conductor on the nose of the anticlinal axis adjacent to basic intrusive complex rocks. This is an example of the geologic

occurrence of the base metal sulphides in the Mattagami district. This, and 14 other anomalous zones, was selected for ground investigations by geological mapping and magnetic, electromagnetic, gravity and geochemical surveys.

18. The ground investigations required about 5-1/2 month's work. An example of the interpretation and analyses of these data, requiring one month's time, is shown on Figure VII. The original scale of this map is 1"=200 feet and represents the 0.3 square mile area along the north flank of the anticline mentioned in the above paragraph. A rating of fifteen such anomalous zones resulted in the selection of seven for testing with two drill holes each (14). Note that practically the only outcrops shown on Figure VII were identified as gabbro and that the base metal sulphide host rocks (volcanic-sedimentary) are covered by alluvium. This was generally true in all of the fifteen areas investigated.

19. Ultimately, six of the anomalous zones were drilled with twelve holes during a period of about two months. The seventh anomalous zone was eliminated on the basis of geologic evaluation derived from drilling results on a nearby area. Figure VIII, a section on line 4E of Figure VII, illustrates the drilling results compared to the ground electromagnetic and gravity curves. Although the gravity results marked the gabbro-volcanic contact well, very small or indefinite mass response was noted over the sulphide conductors. This gravity indication of inadequate mass to suggest large tonnage, plus the sparse base metal sulphides associated with the pyrrhotite and pyrite intersected in the drill holes, eliminated further prospecting for large deposits at moderate depths.

20. Although geological and geophysical techniques applied were successful in detecting and outlining sulphide mineralization, this particular prospect proved to be non-commercial. Many such economic disappointments are to be expected in minerals prospecting and merely demonstrate the difficulties involved in discovery and development of new commercial orebodies.

b. In desert area of abundant outcrop.

21. A contrasting example is furnished by the search for commercial mineralization in desert regions of substantial surface exposure. Under these conditions, geologic interpretation of aerial photography can be extremely useful, particularly the relatively new, but increasingly important applications of color.

22. Pertinent color characteristics vary with locality and climatic conditions, but within given areas, under appropriate conditions, good color aerial photography can result in development of rather precise standards for recognition of structures, lithologic units, alteration haloes and other significant geological details related to mineralization. Desired color accuracy is obtainable only through the most rigid and precise controls of film handling, exposure and processing techniques. Actual experience has shown that lower flight altitudes produce more brillant color rendition and involve less undesirable light absorption effects than higher ones. Even with high sun angles required for color, variations in reflectivity of certain rocks and alteration zones may demand slight compensating exposure variations or filter corrections. Under one set of conditions an exposure of 100th of a second at F:11 using a 6-inch color-corrected Zeiss lens with 9-inch commercial Ektachrome film was found to be optimum for a photo scale of 1:20,000. Antivignetting, haze and batch color compensating filters were used as required.

23. After mounting in clear plastic envelopes, upon which all geologic notations can be made in grease pencil and suitable inks, the positive color transparencies were studied in stereo pairs, in evenly diffused transmitted light having constant color characteristics. By varying the color temperature of the light source with filtering and voltage controls, special color distortion effects were produced to emphasize subtle color differences, critical to the recognition of geologic and mineralogic features of particular interest and significance.

24. Basic detailed geologic mapping in the prospecting equation deserves special attention, since accurate, systematic and something more than purely objective recording of important geological detail is so fundamental in the selection and appraisal of possible ore targets, particularly in regions of good exposures. A rare blend of judgment based on experience and understanding of the genesis of

mineral deposits is required for the recognition of the important significant features to be recorded and assessed. These will vary with each individual environment. The resulting geologic map should not be merely a photographic scale drawing of geologic features, but should emphasize the significant details critical to an accurate understanding of the mineral occurrence under investigation. Because recognition of these features is most difficult in the early prospecting stages, when exposures are most limited, basic geologic mapping should be conducted by well trained and experienced geologists rather than by juniors. Before being entrusted with such responsibilities, geologists in our organizations are thoroughly trained in operating mines in order to become familiar with the geological details and geometric patterns of commercially productive orebodies. Only through experience of being responsible for successful application of geology to daily production problems, can individual talents be developed with acute appreciation for the significant ingredients that combine to form commercial ore concentrations. These talents can then be applied individually or collectively as conditions require in the recognition and development of a new ore discovery.

25. At the El Salvador porphyry copper deposit in the desert region of northern Chile, numerous individual talents available within a large mining organization were applied to a successful appraisal and development of the property into a commercial enterprise. As the geology of El Salvador mine has been described[1] it will not be repeated here, but application of geological methods will be discussed briefly.

26. Discolored zones of leached outcrops and broad alteration haloes were recognizable from ground observations, air reconnaissance and photography. Initial geological mapping at El Salvador was of reconnaissance type on 1 to 10,000 scale. This provided a general picture of the rock patterns and structural features over an area approximately 5 kilometers wide by 7 kilometers long. Gross features, including distribution of major rock units and their general relationships to obvious major structures, leached capping characteristics, and broad patterns of mineralizing activity and attendant alteration were accurately recorded by experienced mine geologists. Subsequent follow-up mapping on 1 to 1,000 and 1 to 500 and even larger scales, was required before a drilling program could be justified. Field observations were sharpened with the aid of microscopic studies and other geological laboratory techniques, thereby increasing the detail of significant lithologic, mineralogic and structural features to be mapped. Important variations within the porphyry complex and other host rocks were recorded together with intricate features of contact relationships.

27. Mapping the distribution of many mineralogical species, such as quartz, sericite, limonites, biotites, chlorite, epidote and clay mineral complexities within the leached capping and alteration haloes resulted in appreciation of important patterns related to the complex structural and mineralisation history of the area. The recognition of important recurring events, commonly associated with ore forming processes, provided a sound geological hypothesis for the initiation of an exploratory drilling campaign directed toward specific favorable geologic targets rather than on a random grid pattern. Indeed, in this case, because of rugged topographic conditions, the shape of the orebody, the extreme depth to ore up to 450 meters below the surface, initial drilling on a grid pattern would have been impractical from both the standpoint of cost and operating techniques available at the time. In addition, the results might have been highly misleading and could have resulted in wasteful misdirection in development work or possibly even abandonment of the project before it had been adequately tested. Drill hole assays alone could not provide an understanding of the geometry and extent of the new ore discovery. This was developed through painstaking recording of all the significant mineralogic and geologic details made available through third dimension penetrations. Additional variations in mineral zoning in the third dimension became evident as penetration depths below the surface were attained. Characteristics and distribution of the sulphide minerals and their relationships to major and minor structures, alteration products, and accompanying gangue minerals were carefully mapped on 1 to 100 scale and plotted on suitable cross sections. Locations of

subsequent exploratory tunnels and eventual underground workings were also influenced by this work. With increasing experience in the area and continued assistance of closely integrated laboratory work, greater accuracy was possible for recognition of characteristics of specific rock types whose features had been obscured through effects of metamorphism, mineralization and alteration.

28. Genetic studies of ore forming processes, including published results of experimental work carried on by government and university geological research laboratories, is being continuously incorporated into improved mapping systems. A well equipped mining company geological research department is dedicated to that end for improvements in efficiency of ore search and the solution of mining geological problems.

29. The El Salvador story is just one of many that emphasize the great gap between initial recognition of numerous anomalous conditions that may exist over broad areas and the integration and application of appropriate techniques leading to the efficient selection, discovery and successful development of a commercial ore deposit.

30. Restrictions of space will not permit complete descriptions and illustrations of other case histories showing the application of the basic concepts of procedure outlined above.

31. It is evident, however, that a thorough knowledge of the geology of ore deposits and good judgment in the evaluation and balancing of geological and geophysical and geochemical data is indispensable at all stages of exploration programs In the later stages good detailed geological data recording and analyses may mean the difference between a discovery and a near-miss. It can also be the difference between mis-evaluation of a potentially commercial deposit and an accurate economic evaluation; and a poorly designed mining operation or a well-engineered one.

Conclusion:

32. In conclusion, as new ore discoveries become more difficult, and exploration requirements more demanding, even greater efforts and achievements may be expected toward improving scientitic techniques of ore finding. Individual prospectors, to be effective, will need broader educational opportunities in the earth sciences and allied fields. Standards for geological training may be expected to improve; expanding to include a better understanding of basic genetic processes of ore formation. Universities and government agencies, with increased laboratory facilities for experimental geological research, can make important contributions to this end, in addition to the all-important development of outstanding individual talents required for effective solution of fundamental geological problems. Commercial mining organizations, through expansion of their industrial applications of scientific and geologic research, must continue to increase their capabilities in well managed integration of specialized talents and improved modern techniques, in the increasingly competitive business of successful ore finding and economic development of orebodies.

Acknowledgments:

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[1] Ref. Swayne, William H. - Trask, Frank Jr., Geology of El Salvador, Mining Engineering, page 344 - (April 1960)

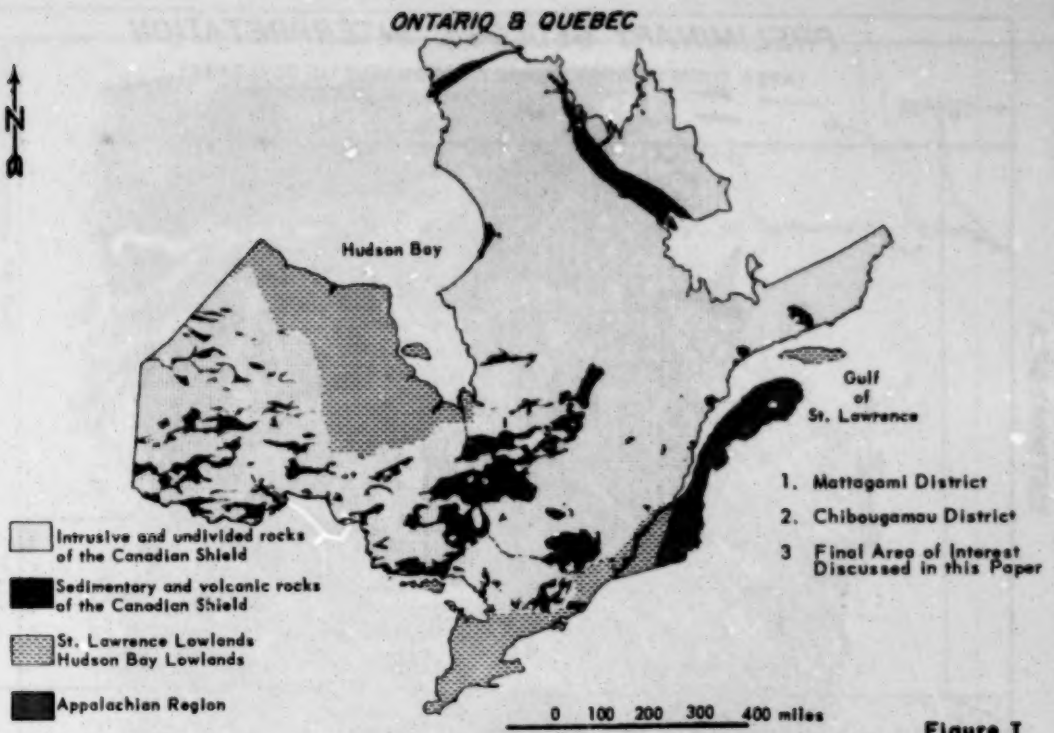

ONTARIO & QUEBEC
N
Hudson Bay
Gulf of St. Lawrence
1. Mattagami District
2. Chibougamau District
3 Final Area of Interest Discussed in this Paper
Intrusive and undivided rocks of the Canadian Shield
Sedimentary and volcanic rocks of the Canadian Shield
St. Lawrence Lowlands
Hudson Bay Lowlands
Appalachian Region
0 100 200 300 400 miles

Figure I

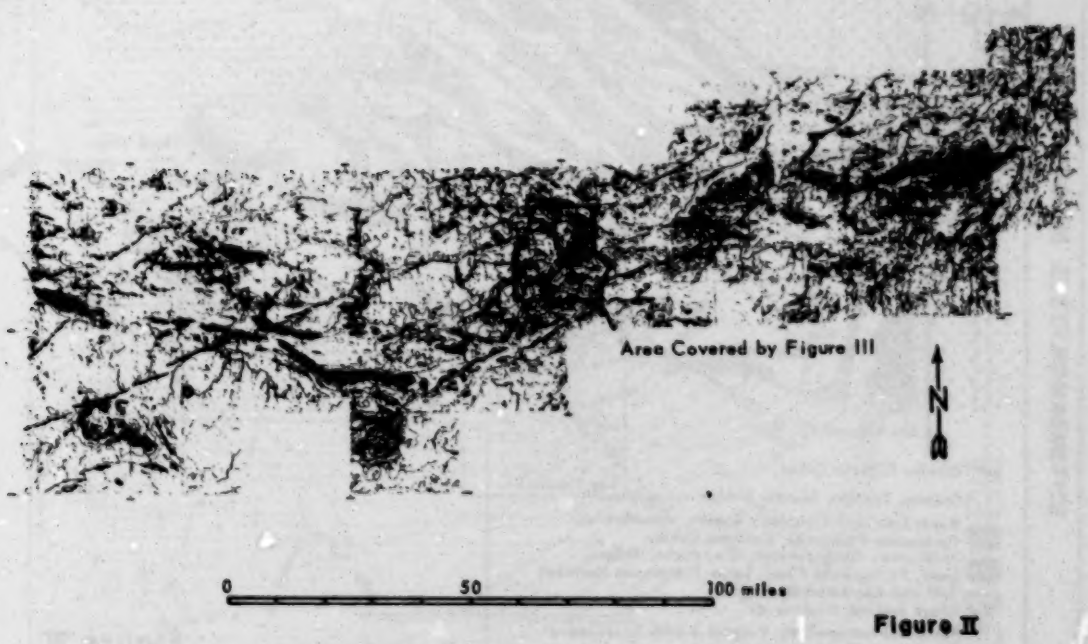


Figure II

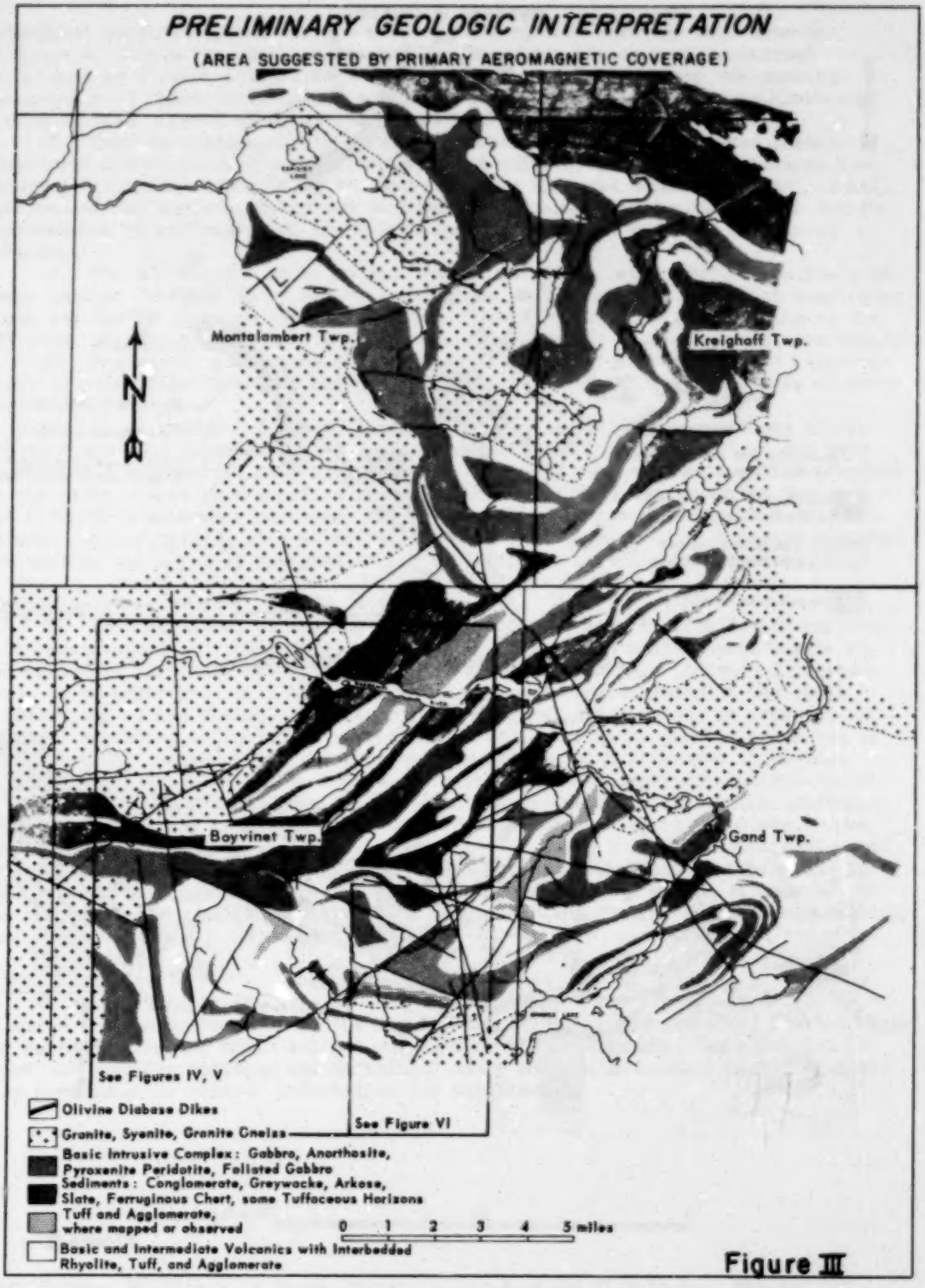

PRELIMINARY GEOLOGIC INTERPRETATION
(AREA SUGGESTED BY PRIMARY AEROMAGNETIC COVERAGE)
Montalembert Twp.
Kreighoff Twp.
Boyvinet Twp.
Gand Twp.
N
See Figures IV, V
See Figure VI
Olivine Diabase Dikes
Granite, Syenite, Granite Gneiss
Basic Intrusive Complex: Gabbro, Anorthosite, Pyroxenite Peridotite, Foliated Gabbro
Sediments: Conglomerate, Greywacke, Arkose, Slate, Ferruginous Chert, some Tuffaceous Horizons
Tuff and Agglomerate, where mapped or observed
0 1 2 3 4 5 miles
Basic and Intermediate Volcanics with Interbedded Rhyolite, Tuff, and Agglomerate

Figure III

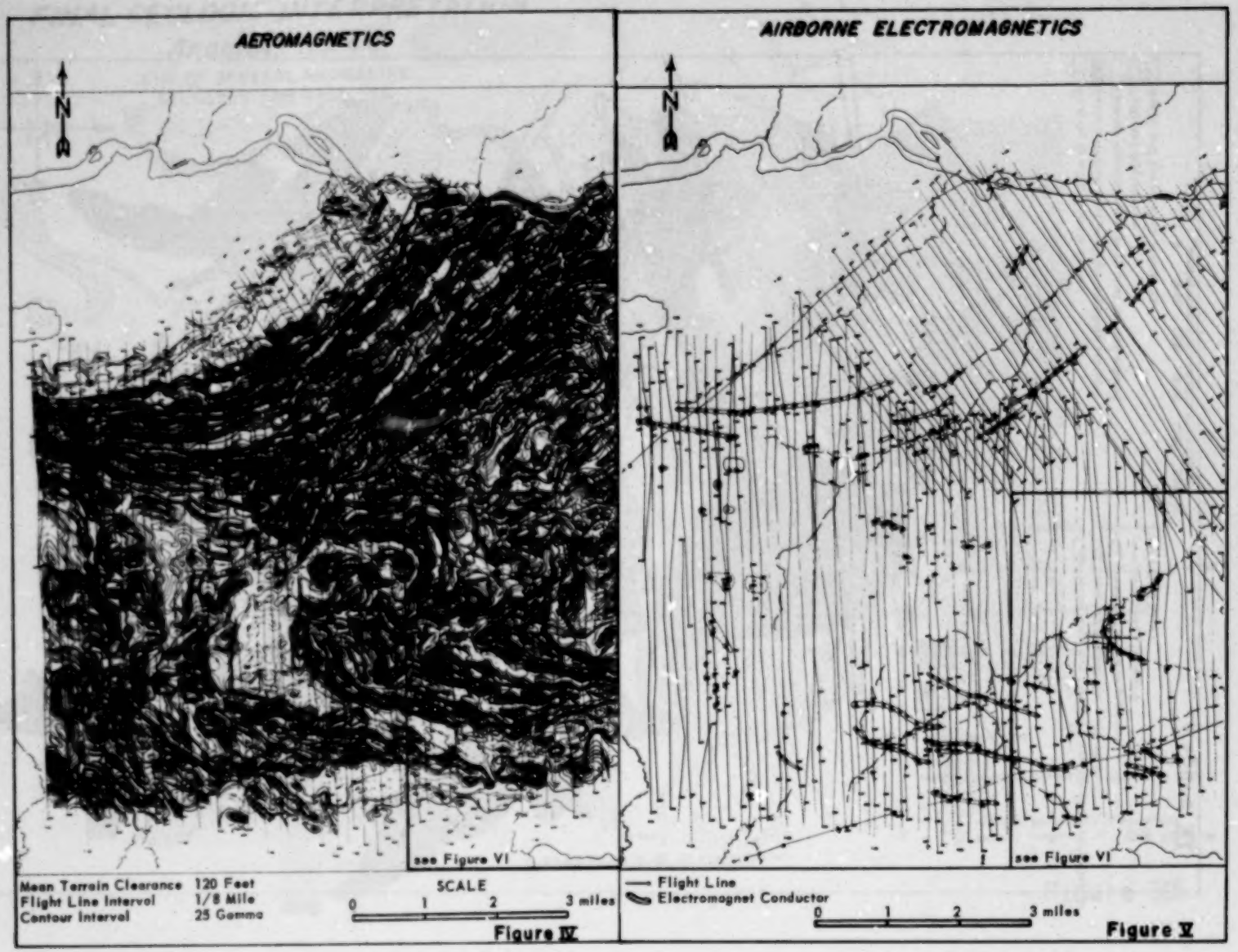


Figure IV

Figure V

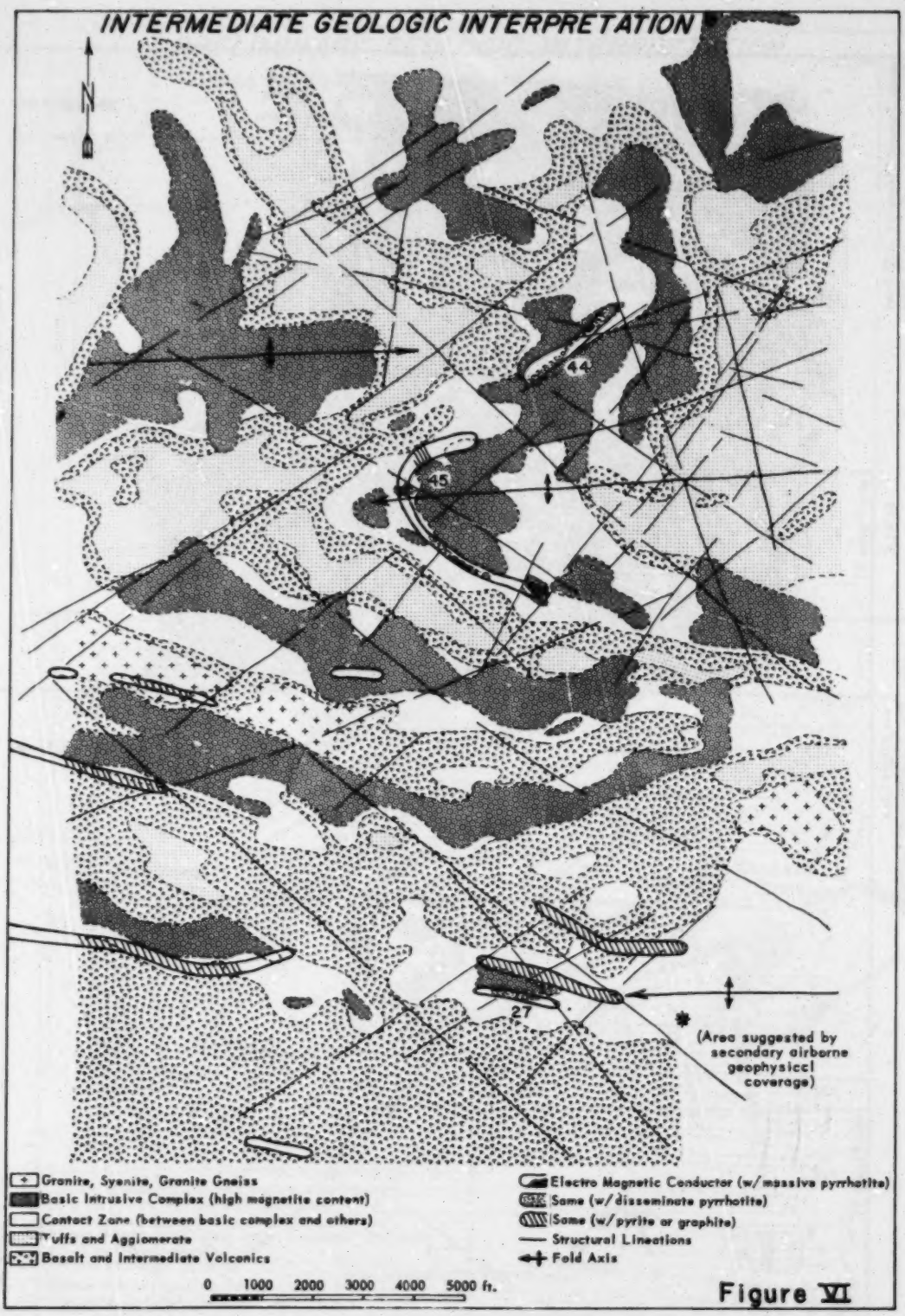

INTERMEDIATE GEOLOGIC INTERPRETATION
N
44
45
27
(Area suggested by secondary airborne geophysical coverage)
Granite, Syenite, Granite Gneiss
Basic Intrusive Complex (high magnetite content)
Contact Zone (between basic complex and others)
Tuffs and Agglomerate
Basalt and Intermediate Volcanics
Electro Magnetic Conductor (w/massive pyrrhotite)
Same (w/disseminate pyrrhotite)
Same (w/pyrite or graphite)
Structural Lineations
Fold Axis
0 1000 2000 3000 4000 5000 ft.

Figure VI

FINAL GEOLOGIC INTERPRETATION

Anomaly No. 44

ONE OF SEVERAL ANOMALIES
SELECTED FOR DRILLING

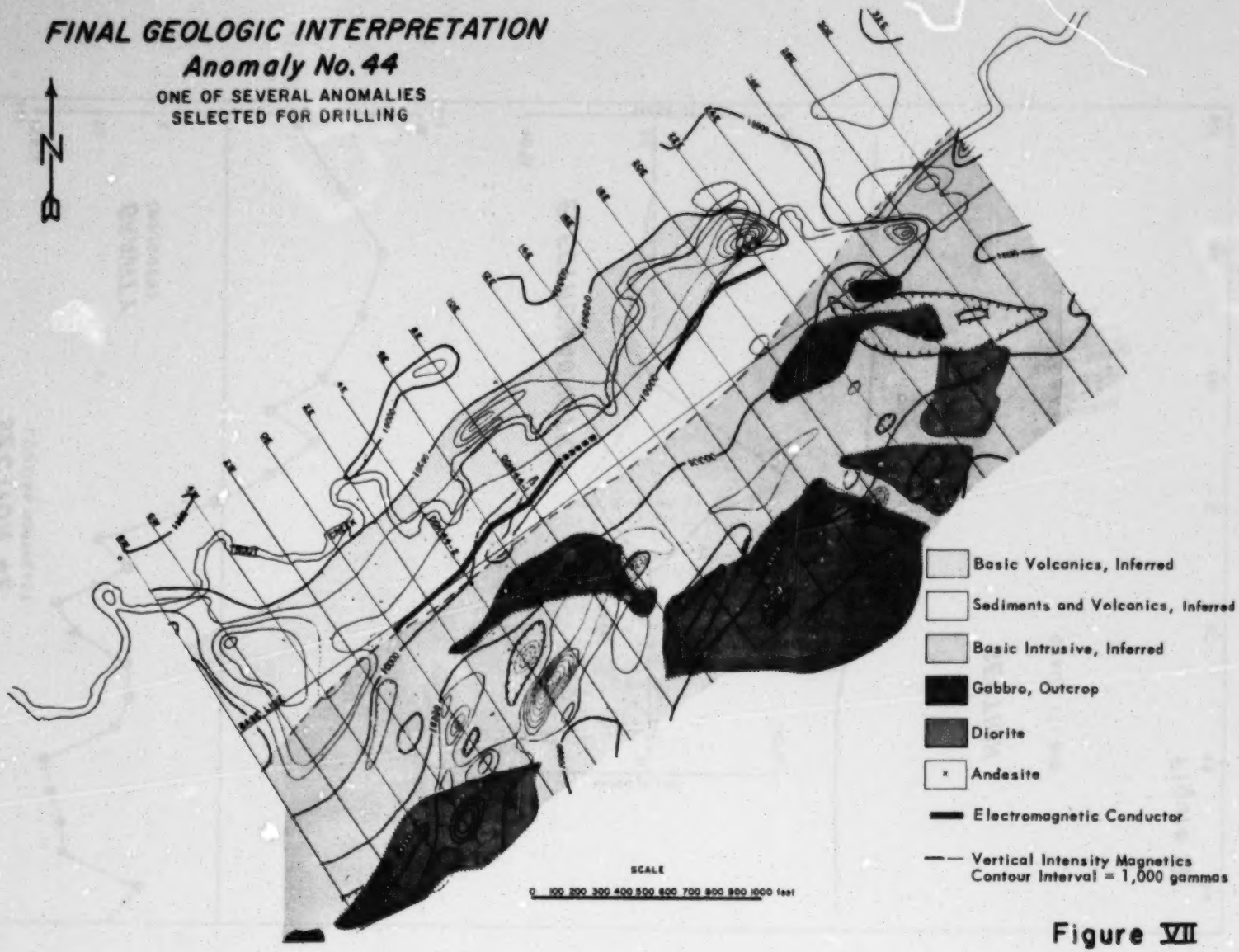
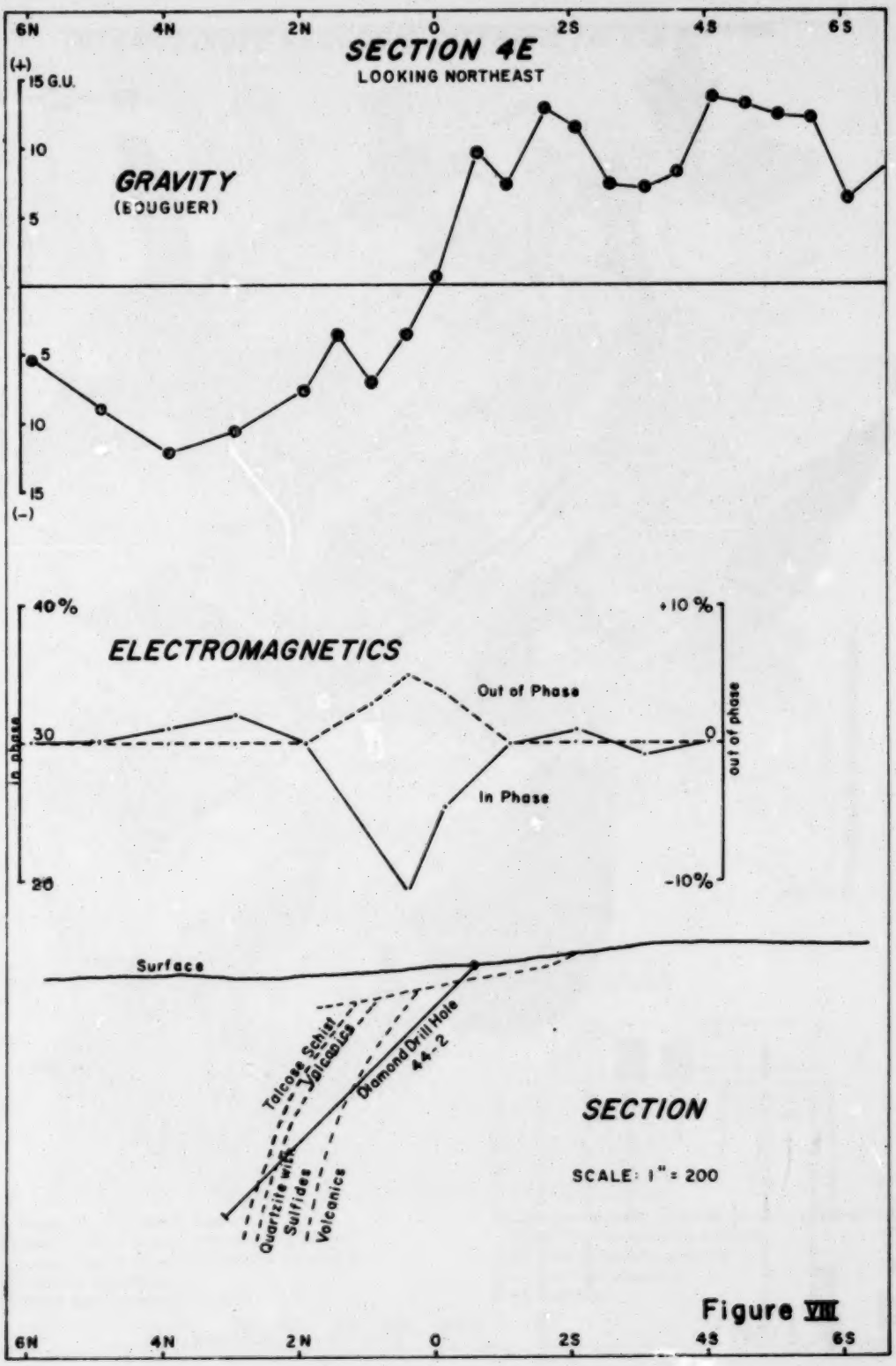


Figure VII


6N
4N
2N
0
2S
4S
6S
SECTION 4E
LOOKING NORTHEAST
(+)
15 G.U.
10
5
GRAVITY
(BOUGUER)
5
10
15
(-)
40%
ELECTROMAGNETICS
Out of Phase
30
In phase
In Phase
20
+10 %
0
out of phase
-10%
Surface
Talcose schist
Volcanics
Quartzite with
Sulfides
Volcanics
Diamond Drill Hole
44-2
SECTION
SCALE: 1" = 200
Figure VIII
6N
4N
2N
0
2S
4S
6S

1628 E - Nov. 1962 - 1, 600